EMULSIFIED ASPHALT CEMENT AS A PARTIAL REPLACEMENT FOR THE MIXING WATER IN PORTLAND CEMENT CONCRETE

by

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B. S., Kansas State University, 1963

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Civil Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1963

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By Delmer H. Schultz

SYNOPSIS

An investigation was conducted to determine experimentally whether or not a significant portion of the mixing water for portland cement concrete could be replaced with asphalt emulsion without affecting adversely the properties of the fresh concrete or the strength of the hardened concrete, and to study the effect of such replacement on the shrinkage characteristics of the hardened concrete.

It was found that when used in conjunction with an air-detraining agent, a commercial, anionic, slow-setting, asphalt emulsion could be used to replace up to 30 per cent of the total mixing water without affecting adversely the properties of the fresh concrete. In the case of lower strength architectural concrete, the strength was increased by the incorporation of asphalt in the mix, but the drying shrinkage and hence the cracking potential was not decreased. In the case of the higher strength structural concrete, the strength was decreased and the drying shrinkage was increased with the incorporation of asphalt in the mix.

INTRODUCTION

Portland cement concrete is a very important structural material throughout the world; widespread effort is being devoted constantly to the improvement of its properties. Cracking is an ever-present problem in both plain and reinforced concrete structures. It not only weakens the concrete structurally, but also reduces its resistance to corrosive elements, increases its permeability, and spoils its appearance. It is therefore desirable to reduce the cracking potential of concrete.

One of the major contributors to this cracking potential is drying shrinkage. The cracking in this case takes place when the shrinkage is restrained. Since all concrete shrinks on drying, and since practically all structural concrete has restraints of one form or another, it follows that structural concrete will almost always have shrinkage cracks present.

Although the mechanism of shrinkage is not entirely understood, several theories have been set forth to explain the phenomenon. Volume changes occur in concrete for various reasons. Powers (5) has described hygrothermal volume changes which have nothing to do with the gaining or losing of water by the concrete; the water in the system merely redistributes itself with changes in temperature in order to achieve equilibrium. Volume changes also occur as a result of the cement-water reaction (6) and the carbonation by atmospheric carbon dioxide of the calcium hydroxide liberated in this reaction (8). However, of main concern here is the volume change caused by water leaving or entering the concrete.

According to Brunauer (2), the first shrinkage that occurs in the drying of cement paste is permanent, but the subsequent shrinking and

swelling of the hardened paste as water is removed or added respectively, is a reversible process. According to Powers and Brownyard (6), shrinkage results when water is withdrawn from the cement gel and is probably due to the solid to solid attraction that tends to draw the solid surfaces together; capillary tension and elastic deformation may also be involved. They consider the water in the cement paste to be of two types, capillary water and gel water. When drying occurs, both are lost simultaneously. However, the resulting volume change is due only to the change in gel water content.

It would seem then that the drying shrinkage potential of portland cement concrete is related directly to the water content or water-cement ratio of the mix. If the water-cement ratio were reduced, there should be less gel water in the paste and hence less distance between the layers of solids initially; there should therefore be less volume change as the gel water leaves the paste.

It is not possible, however, to reduce the water-cement ratio by merely reducing the amount of water used in the mix, since this would destroy the workability of the mix. It is known that approximately 50 per cent of the mixing water used in concrete is there solely for the purpose of providing adequate workability of the mix and is not needed for the hydration process. It would seem feasible then, that the water-cement ratio could be reduced by replacing a portion of the mixing water with a non-volatile substance that would behave similar to water in the mixing process, but that would later harden to a solid or a semi-solid and thus remain as an integral part of the hardened cement paste.

This result would be desirable from another point of view. Since so much of the mixing water is not needed for the hydration reaction, it must then occupy space as excess free water in the paste matrix. As this free water leaves the paste on drying, it leaves air voids which weaken the concrete, since they have no resistance to compression. If these voids were to remain filled with a solid which had some shearing strength of its own, it would both strengthen the concrete in compression and help to resist shrinkage.

One material which would seem to fulfill the above requirements is an emulsion of asphalt cement in water. In time, asphalt cement exposed to the atmosphere cures or oxidizes to a pseudo-solid which has a considerable amount of shearing strength. According to Monismith (3), asphalt emulsions are intimate mixtures of two immiscible liquids, asphalt and water, one of which (asphalt) is evenly dispersed in the other (water) in the form of very fine spherical droplets; photomicrographs of asphalt emulsions show this to be true. This structure of asphalt-in-water emulsions leads to another consideration, namely, the similarity between the finely dispersed spheres of asphalt in an asphalt emulsion and the finely dispersed air bubbles in air-entrained concrete. The fact that the two systems are similar suggests that their effects on fresh concrete might also be similar. A system of finely dispersed air bubbles tends to lubricate the fresh concrete, thereby improving its workability. This effect allows a reduction in total mixing water for the same workability. Since the compressive strength of concrete is inversely proportional to both the water-cement ratio and the air content of the mix, the net change in strength is essentially zero. It is conceivable that an

asphalt-in-water emulsion might have a similar effect on the workability of fresh concrete. However, it should not be expected to decrease the compressive strength of hardened concrete as entrained air does, since it has shearing strength of its own. Also, though emulsified asphalt may increase the durability of the hardened concrete exposed to cyclic freezing and thawing, it will not do so in the same manner as the entrained air bubbles do. The air bubbles provide a space into which the expanding capillary water may escape while it is freezing. The asphalt droplets would not provide such spaces.

Although there are many materials that might be expected to behave similarly, asphalt emulsions have the advantage of being produced commercially on a large scale and are therefore readily available in large quantities almost anywhere in the country; moreover, they are relatively inexpensive and in the proportions anticipated, would not appreciably increase the cost of the concrete. The only detrimental effect that can be foreseen is the fact that many emulsifying agents used to stabilize asphalt emulsions contain neutralized vinsol resin, which is the major constituent of several commercial air-entraining agents for portland cement concrete.

PURPOSE

The purpose of the investigation reported here was to determine experimentally whether or not a significant portion of the mixing water for portland cement concrete could be replaced with asphalt cement in the form of an oil-in-water emulsion without affecting adversely the properties of the fresh concrete or the strength of the hardened concrete, and to study the effect of such replacement on the shrinkage characteristics of the hardened concrete.

SCOPE

Since the work undertaken was intended to be of a purely exploratory nature, the experimental program was designed to contain a minimum number of variables. It was decided that two basic concrete mixes would be proportioned from local materials to yield 28-day compressive strengths of 2500 psi and 5000 psi to represent two broad classes of concrete referred to generally as architectural concrete and structural concrete, respectively. These concretes would then serve as references for comparable concretes containing asphalt cement. The mixing water was to be adjusted with increasing asphalt to yield constant workability of the fresh concretes. The air contents of the fresh concretes, and the strength, shrinkage, and water loss of the hardened concretes were selected as bases for comparison.

MATERIALS

All concrete mixes were made with Lone Star Type I cement, Kaw River sand from Manhattan, Kansas, and a crushed, pseudo-quartzite, coarse aggregate from Lincoln, Kansas. The gradation of the aggregates is shown in Table 1.[1]

The following asphalt emulsions were used in the investigations:

(a) Slow-setting anionic emulsion, designated "SS-1h."
(b) Quick-setting cationic emulsion, designated "85/100 base."
(c) Specially formulated emulsions.

Emulsions (a) and (b) were supplied by the Phillips Petroleum Company, Okmulgee, Oklahoma, and are commercially available. Emulsions (c)

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[1] Tables and figures are contained in the Appendix.

were specially formulated and supplied by McConnaughay Laboratories, Lafayette, Indiana, at the request of William H. Goetz, Professor of Civil Engineering, Purdue University.

An air-detraining agent designated as agent 'A' (composition unknown) was supplied by Protex Industries, Incorporated, Denver, Colorado.

PRELIMINARY STUDIES

Mixes were proportioned by the method recommended by the Portland Cement Association (4). Two basic mixes were thus obtained with nominal 28-day compressive strengths of 2500 psi and 5000 psi. In both cases the slump was 3 inches, and the air content was approximately 1.5 per cent by volume. The proportions by weight for these mixes are as shown in Table 2.

Preliminary investigations reported by Shah (7) using the commercial emulsions (a) and (b) produced negative results in the following way: The slow-setting anionic emulsion contained an emulsifying agent which is also an air-entraining agent with respect to portland cement concrete. The emulsifying agent exists in an amount sufficient to entrain an unacceptably high volume of air when a significant amount of mixing water is replaced with emulsion. Aside from this fact, the emulsion behaved rather well in that it did not break during the mixing process and it did not reduce the workability of the mix, although this latter result can no doubt be attributed in part to the high air content. The cationic emulsion was not sufficiently stable in the presence of the salts that go into solution when portland cement is mixed with water. As a result, this

emulsion broke very quickly and the mix became completely unworkable.

On the basis of Shah's work, it was decided that perhaps a specially formulated emulsion which was better suited for this purpose could be found. The author was referred by Dr. John W. Shupe, Acting Dean of Engineering and Architecture, Kansas State University, to Professor Goetz of Purdue University. Professor Goetz, an expert in the formulation of asphalt emulsions, promptly shipped a sample of specially formulated emulsion. This emulsion contained 60 per cent solids; the nature of the emulsifying agent used was not divulged.

Preliminary investigations were performed replacing up to 10 per cent of the mixing water with emulsion with a reasonable degree of success. However, higher concentrations again entrained large amounts of air with a subsequent loss in strength. Upon receiving and investigating subsequent samples of supposedly the same asphalt emulsion, greatly varied results were obtained in that the air content ranged from 7 to 11 per cent where it had previously ranged from 4 to 5 per cent. A sample of tar emulsion behaved similarly.

Finally, because of the lack of uniformity of successive samples, the probable higher cost, and the probable restricted availability of the specially formulated emulsions, they were set aside in favor of the commercial anionic, slow-setting emulsion for further investigation in view of the possibility of using an air-detraining agent to reduce the air content to an acceptable level.

EFFECT OF ANIONIC SLOW-SETTING EMULSION ON PROPERTIES OF FRESH CONCRETE

All concrete was mixed in a Lancaster counter-current batch mixer, made by Lancaster Iron Works, Lancaster, Pennsylvania, according to the following procedure: The cement, sand, and aggregate were mixed dry for the first half minute in order to blend them thoroughly. Then the water containing the asphalt emulsion was added during the next half minute. The total mixing time was four minutes, and the slump was determined at seven minutes after mixing began. The slump test was performed according to ASTM C 143-58, Standard Method of Test for Slump of Portland Cement Concrete (1), and was kept constant at approximately three inches for all mixes by carefully watching the concrete while mixing and adjusting the amount of mixing water accordingly in each case. Since the asphalt emulsion was completely miscible in water, it was thoroughly mixed with the water before being poured into the mixer. The air-detraining agent was treated in the same way.

After the slump test had been performed, the unit weight and air content of the mix were determined according to ASTM C 138-44, Standard Method of Test for Weight per Cubic Foot of Concrete, and ASTM C 231-60, Standard Method of Test for Air Content of Freshly Mixed Concrete by the Pressure Method (1).

The air content was kept in the range from 3 to 6 per cent by adjusting the amount of air-detraining agent used. Trial mixes for the conditions shown in the following tabulation were made until the desired properties of fresh concrete were obtained:

Condition	Nominal Compressive Strength psi	Amount of Mixing Water Replaced by Emulsion, % by vol.
1		0
1a	2500	10
1b		20
1c		30
2		0
2a	5000	10
2b		20
2c		30

All emulsion replacements referred to in this tabulation are in per cent by volume of the total mixing water used in the reference mix. Since the emulsion was composed of 60 per cent solids, the actual replacements of water by asphalt for conditions a, b, and c were, respectively, 6, 12, and 18 per cent. The results of the tests made on the fresh concrete are presented in Table 3.

EFFECT OF ANIONIC SLOW-SETTING EMULSION ON PROPERTIES OF HARDENED CONCRETE

Whenever the properties of the fresh concrete from a trial mix were within the desired limits, cylindrical strength specimens were cast; from an identical mix, prismatic shrinkage specimens were cast.

The 3- by 6-in. cylindrical strength specimens were cast in waxed cardboard molds according to ASTM C 192-59, Standard Method for Making and Curing Concrete Compression Specimens in the Laboratory (1), and tested according to ASTM C 39-61, Standard Method of Test for Compressive Strength of Molded Concrete Cylinders (1). Twelve cylinders

were prepared for each condition. At ages 1, 3, 7, and 28 days, three samples were tested for each condition and the average strength values were computed. The results of these tests are presented in Table 4, and in Figs. 1 and 2.

The prismatic shrinkage specimens were 4- by 6- by 16-in. A metal stud was cast into each end of each prism to facilitate length measurements. Three such prisms were cast for each condition and stored in a standard curing atmosphere for 16 days. They were then moved to an atmosphere of 50 per cent relative humidity and 70° F. Initial length and weight measurements were made immediately following their removal from the standard curing atmosphere, and changes in length and weight loss were measured at 1, 2, 4, 8, 15, 29, and 55 days thereafter. These data were again reduced to average values for the three specimens of each condition. The results of these tests are presented in Table 5, and in Figs. 3, 4, 5, and 6.

When the shrinkage and weight loss measurements were complete, the prisms were tested for Modulus of Rupture, ASTM C 293-54T, for Modified Cube Strength, ASTM C 116-49, for Strength in Splitting Tension, and for Dynamic Modulus of Elasticity, ASTM C 215-55T (1). The results of these tests made at ages varying from 76 to 83 days, are presented in Table 6, and in Figs. 7, 8, 9, and 10.

DISCUSSION OF RESULTS

The anionic slow-setting asphalt emulsion in conjunction with the air-detraining agent behaved very well during the mixing process in concentrations up to 30 per cent of the mixing water. In trial mixes with greater concentrations, the concrete stiffened considerably, and the asphalt began to precipitate on the concrete tools and mixer. For this reason, replacements of over 30 per cent were not used.

The emulsion contained a considerable amount of air-entraining agent as can be seen from Table 3, in that large increases in the dosage of air-detraining agent were necessary in order to maintain the air content below six per cent with increases in emulsion replacement. The composition of the air-detraining agent is unknown; by observation of the fresh concrete during and after mixing as well as by examination of fractured specimens, it was possible to deduce the manner in which it worked. Apparently, the microscopic, entrained air bubbles were made to coalesce into much larger bubbles which were then forced out of the mix by buoyancy. The fresh concrete bubbled profusely immediately after mixing, and it was easy to see that a great deal of air was being forced out of the mix. It was also visually evident that the hardened concrete contained a great many of these larger bubbles of air. This result suggested that perhaps the real value of the entrained air had been destroyed even though the mixes contained between five and six per cent of air, because it is necessary that entrained air bubbles be small and uniformly dispersed if they are to be effective in inhibiting frost damage. These larger air voids could also weaken the concrete in

compression and in resisting shrinkage, and therefore destroy the advantages of incorporating asphalt in the mix. The results of the various tests seem to confirm this.

According to Fig. 1, Conditions 1a and 1b had higher strength than the control mix, Condition 1, while Condition 1c was about the same as the control mix. This result suggests that the advantages of the asphalt in the mix and the reduced water-cement ratio overcame the disadvantage of the oversize air voids for compressive strength of architectural concrete.

According to Fig. 2, however, all conditions containing asphalt were weaker in compression than the control mix, Condition 2. This result suggests that for structural concrete, the weakening effect of the large air voids is more pronounced than in the lower strength architectural concrete. It could also be that the shearing strength of the asphalt was exceeded at the stress level needed to break the higher strength concrete and therefore did not contribute to the strength of the specimen. In any case, the loss in strength was higher than could be tolerated to make the process feasible for higher strength concrete.

Figures 3 and 4 show that in the cases of both high and low strength concrete, the mixes containing asphalt possessed greater shrinkage potential than the control mixes. Some of the roughness in the curves can be attributed to the variations in temperature and relative humidity that were observed in the laboratory where the specimens were stored during the drying period. The adverse results here again may be attributed to the large air bubbles present in the concrete since these bubbles could effectively reduce the resistance of the concrete to shrinkage, even though

there was an appreciable reduction of the water-cement ratios of the mixes. In addition to reducing the net cross-sectional area resisting shrinkage, these bubbles may also provide sinks for gel water. According to Powers and Brownyard (6), any loss of gel water is accompanied by a reduction in volume. The weight loss curves in Figs. 5 and 6 lend support to this idea. In all cases, the mixes with asphalt in them lost less weight and hence less water on drying than did the control mixes.

The trends of the strength tests performed on the prisms as shown in Figs. 7, 8, 9, and 10 are very similar to the trends of the cylinder compressive strength data shown in Figs. 1 and 2.

CONCLUSIONS AND RECOMMENDATIONS

Using the same materials and techniques as were used in this experiment, it would not seem advantageous to replace a portion of the mixing water in portland cement concrete with asphalt emulsion. However, several factors should be considered before abandoning the whole idea.

First of all, it should be remembered that the anionic slow-setting emulsion used in this experiment was not designed for this purpose. In fact, it was designed for use in the construction of pavements where the emulsion must break in order for it to combine with the aggregates to form a monolithic slab. In our case, it would be best if the emulsion were never to break, although it must do so eventually due to desiccation. Even though it appeared to be evenly distributed throughout the paste

matrix, it is possible that the asphalt precipitated on the aggregate particles, thus hampering the paste-to-aggregate bond and hence weakening the concrete.

The most obvious and possibly the most vital problem was the large amounts of air entrained by the emulsifying agent. Even though the problem of excess air content was alleviated by the use of an air-detraining agent, the larger air bubbles thus formed were probably the greatest single factor in producing the negative results that were obtained.

There are two possible areas which may be investigated further. The first is that of discovering or formulating an asphalt emulsion which is extremely stable in the presence of the salts that go into solution when portland cement is mixed with water, and which is stabilized with an emulsifying agent which is not an air-entraining agent with respect to portland cement concrete.

The other possibility is that of finding another method of eliminating the excess entrained air, which could perhaps be done either by preventing the air bubbles from forming initially, or by eliminating them after they have formed without forming the larger bubbles encountered in this experiment. The scrubbing action which causes the tiny air bubbles to form is believed to be connected primarily with a particular size fraction of sand in the mix. If this size fraction were to be removed, it is possible that no excessive air entrainment would take place no matter how much air-entraining agent were present.

In the opinion of the writer, if either the specially formulated emulsion or the special method of air-detrainment described above could be obtained, the partial replacement of the mixing water in portland cement concrete with asphalt emulsion might be successfully accomplished with advantageous results.

ACKNOWLEDGMENT

This work was done under a fellowship sponsored by the Phillips Petroleum Company, Bartlesville, Oklahoma. The author also wishes to express his sincerest appreciation to Dr. John W. Shupe, Acting Dean of Engineering and Architecture, Kansas State University, for his interest in the project, to Professor William H. Goetz of Purdue University, for his interest in the project and his cooperation in preparing specially formulated emulsions for the project, and to his advisor, Dr. Cecil H. Best for his guidance and encouragement during the laboratory work and the writing of this thesis.

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APPENDIX

Table 1. Gradation of aggregates.*

Sieve Size	Kaw River Sand Cumulative % retained	Lincoln Quartzite Cumulative % retained
3/4"	0.0	2.0
(1/2")	(0.0)	(57.2)
3/8"	0.0	82.5
No. 4	1.2	98.8
No. 8	10.6	100.0
No. 16	39.2	100.0
No. 30	70.2	100.0
No. 50	94.2	100.0
No. 100	99.8	100.0
(No. 200)	(100.0)	(100.0)
Fineness Modulus	3.15	6.83

* Sieve analysis performed according to ASTM C 136-46 (1).

Table 2. Proportions by weight of basic mixes.

Material	Nominal 2500 psi f'_c	Nominal 5000 psi f'_c
Cement	1.00	1.00
Sand	3.68	2.81
Coarse Aggregate	4.50	2.80
Water-Cement Ratio	0.874	0.614

Table 1
and Table 2

Table 3. Properties of fresh concrete.

Condition	Mixing Water Replaced by Asphalt (% by wt.)	Net Water-cement ratio (by wt.)	Amount of Air-detraining Agent used (drops)	Slump (inches)	Air Content (% by vol.)	Unit Weight (lb/ft^3)
1	0	0.874	0	3.50	2.0	144.0
1a	6	0.710	11	2.75	5.6	139.0
1b	12	0.683	15	2.75	6.0	138.0
1c	18	0.713	22	4.50	5.9	137.5
2	0	0.614	0	3.50	1.2	146.0
2a	6	0.525	11	3.75	5.5	140.0
2b	12	0.520	17	3.00	5.5	140.0
2c	18	0.513	22	2.75	4.5	141.0

Table 4. Cylinder compressive strength at various ages.

Condition	Strength of 3 by 6-inch cylinders in compression; each value is the average of three cylinders.							
	1 day		3 days		7 days		28 days	
	psi	%	psi	%	psi	%	psi	%
1	230	100	840	100	1530	100	2590	100
1a	270	117	1200	143	2020	132	3040	117
1b	370	161	1140	136	1950	127	2760	106
1c	210	91	800	95	1510	99	2540	98
2	430	100	2230	100	3700	100	5180	100
2a	570	133	1990	89	3080	83	4090	79
2b	550	128	1900	85	3110	84	4340	84
2c	670	156	2110	95	2930	79	3460	67

Table 5. Shrinkage and weight loss data.

Condition	Shrinkage strain in micro-in. /in.							Weight loss in %						
	Drying time in days							Drying time in days						
	1	2	4	8	15	29	55	1	2	4	8	15	29	55
1	50	63	100	113	188	269	313	1.08	1.45	1.87	2.32	2.73	3.15	3.43
1a	137	125	144	169	218	331	369	0.79	1.02	1.31	1.64	1.96	2.33	2.52
1b	87	69	75	94	162	262	319	0.60	0.85	1.09	1.34	1.67	1.98	2.19
1c	69	56	69	94	162	281	325	0.77	0.99	1.24	1.55	1.87	2.18	2.44
2	87	87	94	125	194	288	313	0.55	0.74	1.03	1.31	1.63	1.95	2.17
2a	81	100	131	156	231	312	319	0.45	0.60	0.78	1.01	1.24	1.46	1.63
2b	69	75	94	119	200	294	319	0.43	0.60	0.78	0.99	1.23	1.46	1.65
2c	56	63	95	131	206	312	350	0.43	0.59	0.75	0.96	1.16	1.39	1.55

Table 6. Properties of prisms.

Condition	Dynamic Modulus of Elasticity at age 76 da. (psi x 10^{-6})	Modulus of Rupture at age 83 da. (psi)	Modified Cube Strength at age 85 da. (psi)	Splitting Tension Strength at age 83 da. (psi)
1	4.19	680	3430	250
1a	4.24	770	3760	360
1b	4.29	730	3910	330
1c	3.80	710	3230	280
2	5.03	880	6880	480
2a	4.63	870	5510	440
2b	4.71	800	5410	430
2c	4.72	840	6100	430

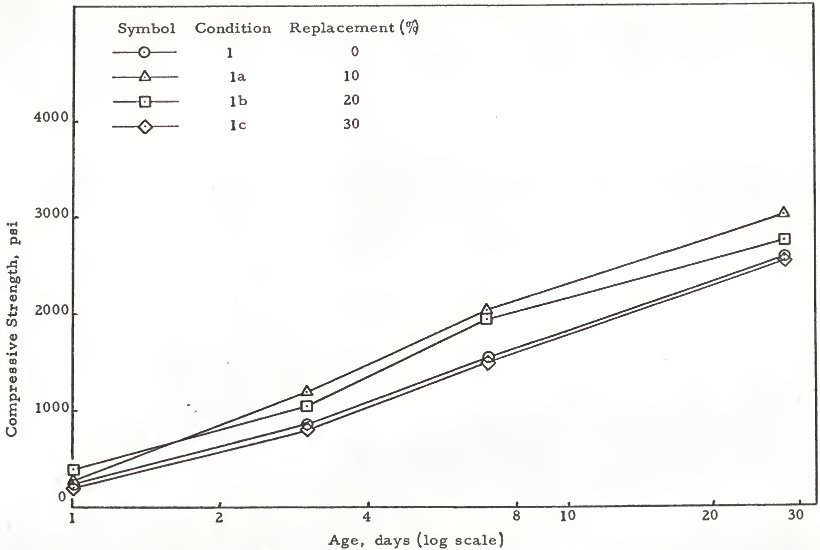

Fig. 1. The effect of the replacement of mixing water with asphalt emulsion on the compressive strength of architectural concrete.

Fig. 1

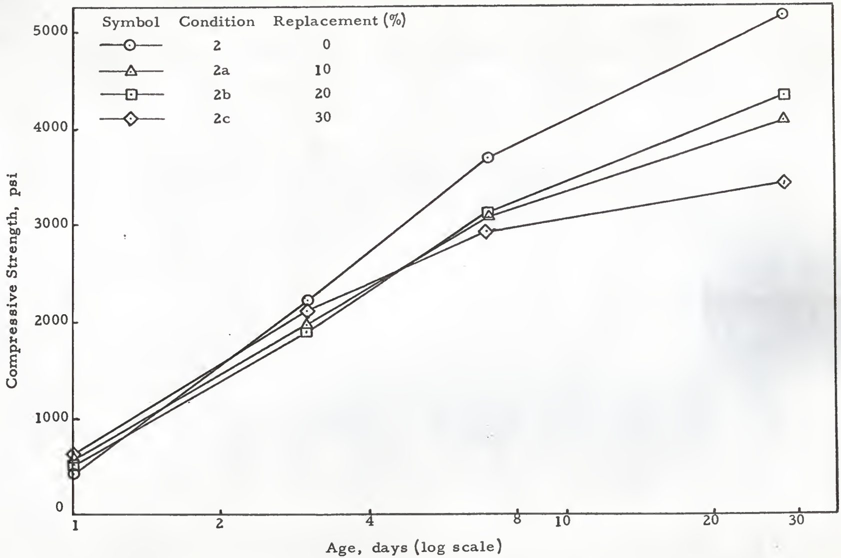

Fig. 2. The effect of the replacement of mixing water with asphalt on the compressive strength of structural concrete.

Fig. 2

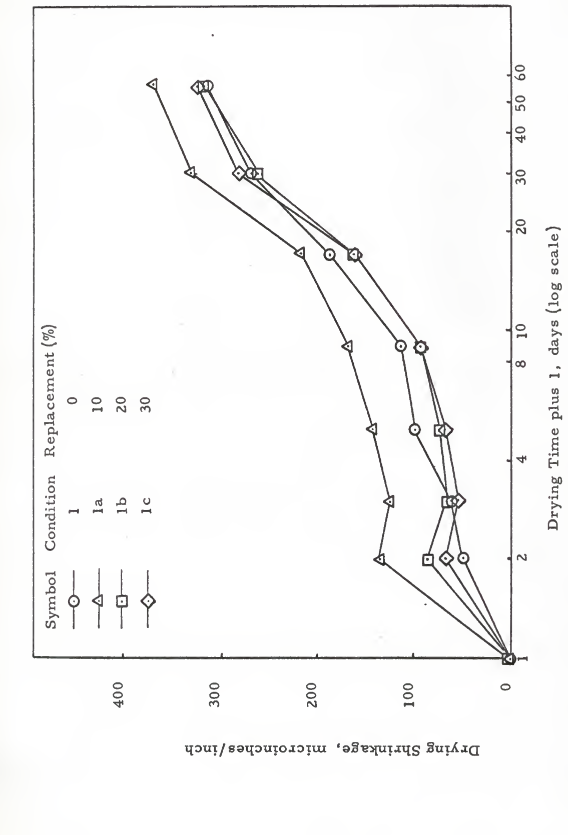

Fig. 3. The effect of the replacement of mixing water with asphalt emulsion on the drying shrinkage of architectural concrete.

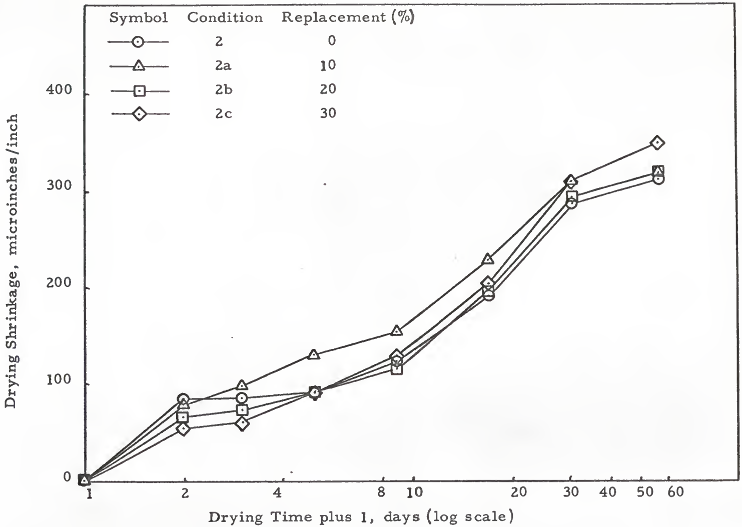

Fig. 4. The effect of the replacement of mixing water with asphalt emulsion on the drying shrinkage of structural concrete.

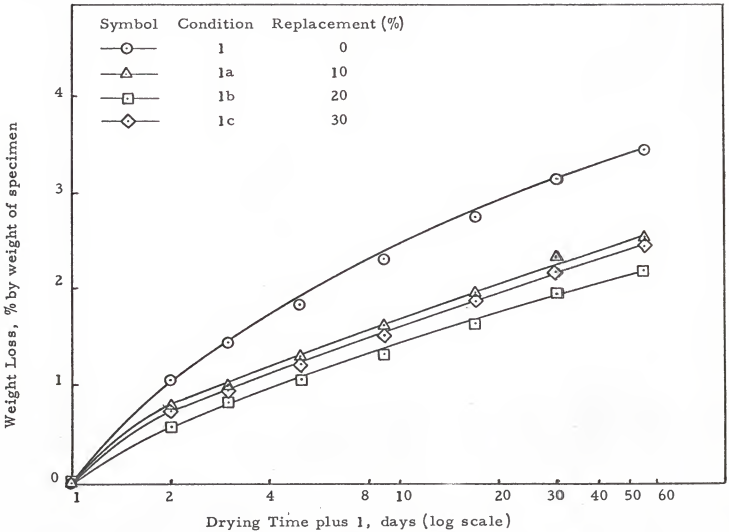

Fig. 5. The effect of the replacement of mixing water with asphalt emulsion on the weight loss of architectural concrete.

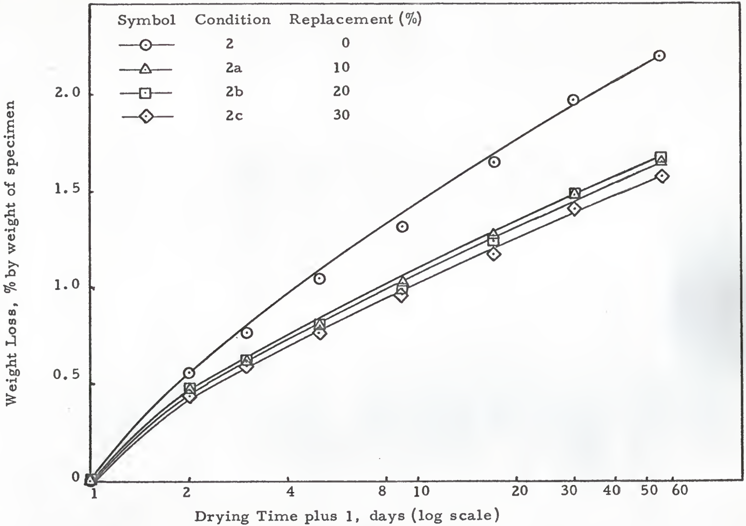

Fig. 6. The effect of the replacement of mixing water with asphalt emulsion on the weight loss of structural concrete.

Fig. 6

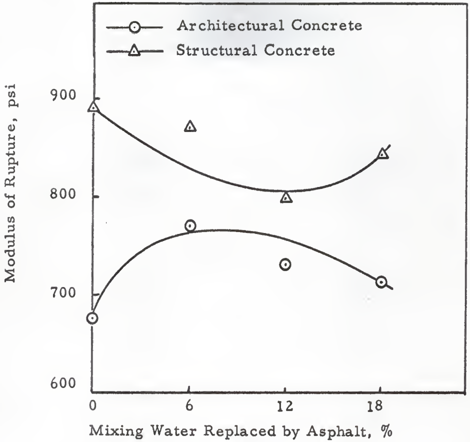

Fig. 7. The effect of the replacement of mixing water with asphalt emulsion on modulus of rupture.

Fig. 7

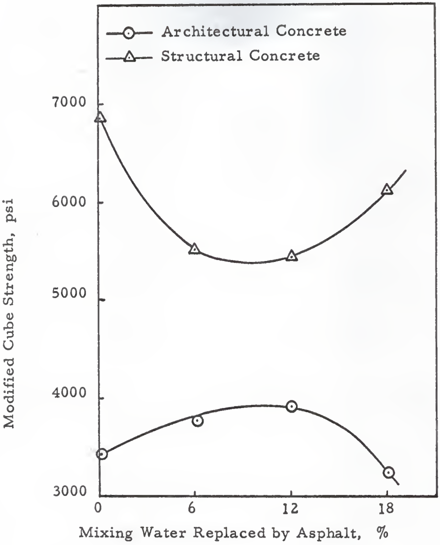

Fig. 8. The effect of the replacement of mixing water with asphalt emulsion on modified cube strength.

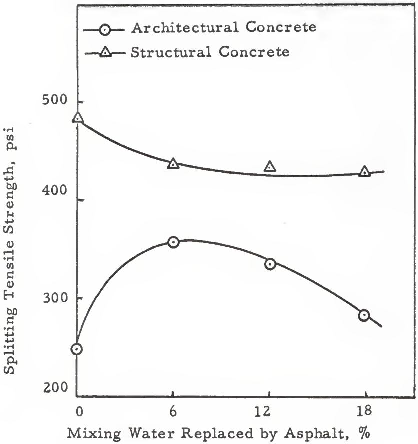

Fig. 9. The effect of the replacement of mixing water with asphalt emulsion on strength in splitting tension.

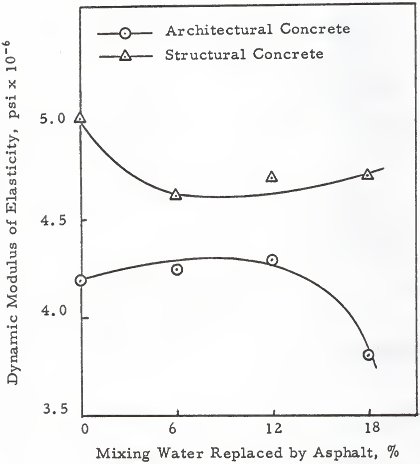

Fig. 10. The effect of the replacement of mixing water with asphalt emulsion on dynamic modulus of elasticity.

Fig. 10

EMULSIFIED ASPHALT CEMENT AS A PARTIAL REPLACEMENT FOR THE MIXING WATER IN PORTLAND CEMENT CONCRETE

by

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B. S., Kansas State University, 1963

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Civil Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1963

A large portion of the mixing water in portland cement concrete is there solely for the purpose of providing adequate workability of the mix. As this excess water leaves the cement paste on drying, it causes a volume change or shrinkage which, when restrained, will result in cracks. If that portion of the mixing water needed only to promote workability of the mix, could be replaced with a non volatile material which would remain as a solid or semi-solid having some shearing strength of its own, the shrinkage potential and thus the cracking potential could possibly be reduced. Asphalt cement in the form of an oil-in-water emulsion is such a material.

An investigation was conducted to determine experimentally whether or not a significant portion of the mixing water for portland cement concrete could be replaced with asphalt emulsion without affecting adversely the properties of the fresh concrete or the strength of the hardened concrete, and to study the effect of such replacement on the shrinkage characteristics of the hardened concrete.

It was found that when used in conjunction with an air-detraining agent, a commercial, anionic, slow-setting, asphalt emulsion could be used to replace up to 30 per cent of the total mixing water without affecting adversely the properties of the fresh concrete. In the case of lower strength architectural concrete, the strength was increased by the incorporation of asphalt in the mix, but the drying shrinkage and hence the cracking potential was not decreased. In the case of the higher strength structural concrete, the strength was decreased and the drying shrinkage

was increased with the incorporation of asphalt in the mix.

Probably the greatest single factor responsible for these adverse results was the formation of large air bubbles from the microscopic entrained air bubbles by the air-detraining agent. These oversize air bubbles reduce the compressive strength of the concrete, reduce the net cross-sectional area resisting shrinkage and provide sinks for gel water, the loss of which induces shrinkage.

On the basis of this work, it is suggested that a positive reduction in the shrinkage potential of portland cement concrete might be achieved by replacing a portion of the mixing water with an emulsified asphalt cement if an emulsified asphalt cement which does not entrain air in portland cement concrete were developed.